

The Fluid Mechanics of Gravitational Structure Formation

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ABSTRACT

The standard model for gravitational structure formation in astrophysics, astronomy, and cosmology is questioned. Cold dark matter (CDM) hierarchical clustering cosmology neglects particle collisions, viscosity, turbulence and diffusion and makes predictions in conflict with observations. From Jeans 1902 and CDMHC, the non-baryonic dark matter NBDM forms small clumps during the plasma epoch after the big bang that “cluster” into larger clumps. CDM halo clusters collect the baryonic matter (H and He) by gravity so that after 300 Myr of “dark ages”, huge, explosive (Population III) first stars appear, and then galaxies and galaxy clusters. Contrary to CDMHC cosmology, “hydro-gravitational-dynamics” HGD cosmology suggests the diffusive NBDM material cannot clump and the clumps cannot cluster. From HGD, the big bang results from an exothermic turbulent instability at Planck scales (10^{-35} m). Turbulent stresses cause an inflation of space and fossil density turbulence remnants that trigger gravitational instability at protosupercluster masses (10^{46} kg) in the H-He plasma. These fragment along plasma turbulence vortex lines to form protogalaxy masses (10^{42} kg) just before the transition to gas. The gas has $\times 10^{-13}$ smaller viscosity, so it fragments at planetary and globular-star-cluster masses (10^{25} and 10^{36} kg) to form the baryonic dark matter (BDM). Observations from the Hubble Space Telescope show protogalaxies (PGs) in linear clusters reflecting their likely fragmentation on plasma vortex lines. From merging BDM planets, these PGs gently form small stars in globular clusters ≤ 1 Myr after the big bang without the dark ages, superstars, or reionization of CDM cosmology.

Subject headings: turbulence: big bang, fossil—cosmology: theory, observations—galaxies: dark matter, star formation

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1. Introduction

The standard cold dark matter hierarchical clustering cosmology (CDMHCC) conflicts with fluid mechanics theory, and with astronomical observations. CDMHCC is based on the Jeans acoustic criterion for gravitational structure formation (Jeans 1902; Jeans 1929). According to the Jeans theory, density fluctuations $\delta\rho$ on scales smaller than the Jeans length $L_J = (V_S/\rho G)^{1/2}$ are stabilized by “pressure support”, where G is Newton’s gravitational constant and V_S is the speed of sound in the gas or plasma. Neither the Jeans theory nor the pressure support justification withstand scrutiny by more modern fluid mechanical methods that include viscosity, diffusivity, turbulence, turbulent mixing, stratification effects and fossil turbulence (Gibson 1996). Concepts of “collisionless fluid mechanics” developed to support CDMHCC (Binney & Tremaine 1987) are also questionable, from a similar set of questionable assumptions, and are in conflict with observations that show strong frictional effects exist in galaxy interactions (Gibson & Schild 2003) and that the baryonic dark matter of galaxies consists of Jeans-mass clumps of earth-mass planets (Schild 1996; Gibson 1996).

In the hot plasma epoch of the early universe less than 300 000 years ($t = 10^{13}$ s) after the big bang, the speed of sound $V_S = c/3^{1/3}$ is of order the speed of light c . No plasma structure can form in the plasma epoch by the Jeans acoustic criterion because the Jeans length scale exceeds the horizon scale, $L_J \geq L_H = ct$, where L_H is the scale of causal connection. Information about density fluctuations on scales larger than L_H cannot be transmitted in time to produce gravitational instability because information speed cannot exceed light speed according to Einstein’s theory. However, observations of temperature anisotropies in the cosmic microwave background clearly show well developed gravitational structures existed at the $t = 10^{13}$ s time of the plasma to gas transition (Gibson 2004; Gibson 2005).

The concept of “cold dark matter” was invented to resolve the dilemma. It was assumed that a massive population of virtually collisionless non-baryonic material was somehow created during the nucleosynthesis epoch with particle speeds less than c . This “CDM” material condensed into stable clumps, or “halos”, with a mass determined by the Jeans scale and density at its time of creation. From CDMHC, CDM halos are gravitationally bound and merge with each other to form larger and larger halos in the process of “hierarchical clustering”. From HGD, CDM halos are diffusively unstable and would be shredded into particles by tidal forces of a clustering event (Gibson 2006).

From CDMHC, these massive CDM halos then collect the baryonic matter into their growing gravitational potential wells and force the formation of stars, galaxies, galaxy clusters, and eventually superclusters of galaxies, in that order. The acoustic peak in the cosmic microwave background spectrum is often cited as evidence of primordial plasma oscillations in CDM halo wells. From HGD, the CMB acoustic peaks reflect the sonic speed limit of

rarefaction waves produced by gravitational fragmentation of the viscous, expanding plasma as protosupercluster voids formed at density minima.

The Jeans 1902 acoustic criterion for gravitational instability is flawed by a variety of unwarranted assumptions. Jeans assumed self-gravitational condensation of a collisionless, inviscid, ideal, fluid governed by Euler’s momentum equations with Vlasov gravity, neglecting nonlinear effects and any effects of diffusion. Even the fluid density was neglected to get a solution to these oversimplified equations in the “Jeans’ Swindle” (Binney & Tremaine 1987, p287). All these assumptions are highly inappropriate for the expanding superviscous primordial plasma and superdiffusive non-baryonic materials produced by the big bang. These flaws have been pointed out and corrected in a series of papers (Gibson 1996; Gibson 2000; Gibson 2004; Gibson 2005) leading to a fluid mechanical model for gravitational structure formation and cosmology termed “hydro-gravitational-dynamics” or HGD (Gibson 2006).

According to HGD, gravitational structure formation is guided by viscous, turbulent, and diffusional fluid mechanics, stratified turbulence, and rarely by acoustics. The big bang is identified as the first turbulent combustion (Gibson 2005). Inflation is driven by big bang turbulent Reynolds stresses, and produces the first fossil turbulence (Gibson 2004), which seeds nucleosynthesis and provides density fluctuations to seed the first formation of gravitational structures by fragmentation at density minima. The first structures are protosuperclusters starting at $t = 10^{12}$ s when the viscous Schwarz scale matches the horizon scale (Gibson 1996).

New observations in a widening range of frequency bands with spectacular improvements in spatial and temporal resolution from ground and space telescopes give a rising flood of contradictions with CDMHCD that can be easily explained or were predicted by HGD cosmology.

In the following, HGD cosmology is reviewed in §2. Comparisons to observations are discussed in §3. Finally, conclusions are presented, §3.

2. Hydro-Gravitational-Dynamics Theory

The hydro-gravitational-dynamics theory of gravitational structure formation covers a wide range of length scales (Table 1) from the big bang Planck scale $L_P = 1.62 \times 10^{-35}$ m of quantum gravitational instability to the present horizon scale $L_H \approx 10^{26}$ m. The Planck temperature $T_P = [c^5 \hbar G^{-1} k^{-2}]^{1/2} = 1.40 \times 10^{32}$ K is so large that turbulence and turbulent mixing are needed to produce entropy and make the process irreversible.

Only Planck particles and Planck anti-particles can exist at such temperatures, plus their spinning combinations (Planck-Kerr particles), so the viscosity is low ($5 \times 10^{-27} \text{ m}^2\text{s}^{-1}$) and the Reynolds number is high ($\leq 10^6$). Planck-Kerr particles are the smallest possible Kerr (spinning) black holes. They represent the big bang equivalent of positronium particles formed from electrons and positrons during the pair production process that occurs at 10^9 K supernova temperatures. Prograde accretion of Planck particles by Planck-Kerr particles can release up to 42% of the Planck particle rest mass $m_P = [chG^{-1}]^{1/2}$, resulting in the highly efficient exothermic production of turbulent Planck gas (Gibson 2004; Gibson 2005). Large negative turbulent Reynolds stresses $\tau_P = [c^{13}h^{-3}G^{-3}]^{1/2} = 2.1 \times 10^{121} \text{ m}^{-1}\text{s}^{-2}$ rapidly stretch space until the turbulent fireball cools from $T_P = 1.4 \times 10^{32} \text{ K}$ to the strong force freeze-out temperature $T_{SF} \approx 10^{28} \text{ K}$ so that quarks and gluons can form. Besides Planck particles, the smallest possible Schwarzschild (non-spinning) black hole, only magnetic monopole particles are possible in the big bang turbulence temperature range (Guth 1997).

Gluon viscosity damps the big bang turbulence and increases negative stresses and the rate of expansion of space. Turbulence and viscous stresses combine with false vacuum energy in the stress energy tensor of Einstein's equations to produce an exponential expansion of space (inflation) by a factor of about 10^{25} in the time range $t = 10^{-35} - 10^{-33} \text{ s}$ (Guth 1997). Fossil temperature turbulence patterns produced by the big bang and preserved by nucleosynthesis and cosmic microwave background temperature anisotropies indicate a similar large value (10^5) for the big bang turbulence Reynolds number (Bershadski and Sreenivasan, personal communication 2005). Only small, transitional Reynolds numbers $c^2t/\nu \approx 10^2$ are permitted by photon kinematic viscosity $\nu = 4 \times 10^{26} \text{ m}^2\text{s}^{-1}$ at the time ($t = 10^{12} \text{ s}$) of first structure (Gibson 2000).

Gluon, neutrino, and photon viscosities dominated momentum transport and prevented turbulence during the electroweak, nucleosynthesis, and energy dominated epochs before $t = 10^{11} \text{ s}$, and also the formation of gravitational structures. Soon after this beginning of the matter dominated epoch the neutrinos ceased scattering on electrons and became super diffusive. Neutrinos were produced in great quantities at the 10^{-12} s electroweak transition that may still exist as part, or most, of the non-baryonic dark matter that dominates the mass of the universe. Momentum transport became dominated by photon viscosity, with the possibility of weak turbulence (Gibson 2000; Gibson 2006).

The conservation of momentum equations for a fluid subject to viscous, magnetic and other forces is

$$\frac{\partial \vec{v}}{\partial t} = -\nabla B + \vec{v} \times \vec{\omega} + \vec{F}_g + \vec{F}_\nu + \vec{F}_m + \vec{F}_{etc}. \quad (1)$$

where $B = p/\rho + v^2/2$ is the Bernoulli group, p is pressure, ρ is density, \vec{v} is velocity, t is time, $\vec{\omega}$ is vorticity, \vec{F}_m is magnetic force, and $\vec{F}_{etc.}$ are miscellaneous other forces. In the

early universe, ∇B , \vec{F}_m and $\vec{F}_{etc.}$ are small compared to the inertial-vortex force $\vec{v} \times \vec{\omega}$ that causes turbulence and the viscous force \vec{F}_ν and gravitational force \vec{F}_g .

When viscous and turbulence forces as well as diffusion are taken into account, the HGD cosmological criterion for gravitational instability at scale L becomes

$$L_H \geq L \geq L_{SX_{max}} = \max[L_{SV}, L_{ST}, L_{SD}] \quad (2)$$

where L_H and the Schwarz scales L_{SV}, L_{ST}, L_{SD} are included in summary Table 1.

The initial stages of gravitational instability are very gentle, driven by either positive or negative density variations $\delta\rho$. All forces other than \vec{F}_g on the right hand side of the momentum equations vanish. Pressure support cannot prevent gravitational instability because any forces from enthalpy p/ρ gradients are perfectly balanced by gradients of kinetic energy $v^2/2$ as the fluid starts to move ($\nabla B = 0$). Because the universe is uniformly expanding with rate-of-strain $\gamma \approx t^{-1}$, gravitational condensations on density maxima are inhibited by the expansion but gravitational fragmentations at density minima are enhanced. The first gravitational structures occurred by fragmentation at density minima when the horizon scale L_H increased to exceed the plasma Schwarz scales, which were all nearly equal in the low Reynolds number hot plasma epoch, $L_{ST} \approx L_{SV} \approx L_{SD}$.

In the turbulent primordial plasma, maximum stretching rates and the first fragmentation should occur along vortex lines of the turbulence, as shown in Figure 1. The large initial density ρ_0 of the plasma is preserved as a fossil by the density of the protogalaxies $\rho_{PG} \approx \rho_0$ and the protoglobularclusters $\rho_{PGC} \approx \rho_{GC} \approx \rho_0$.

3. Comparison to Observations

Observations relevant to the formation of gravitational structures in the early universe are appearing at a rapid pace from many space satellites and highly refined ground based telescopes. Figure 2 contrasts the HGD and CDMHC interpretations of the cosmic microwave background observations of the Wilkinson Microwave Anisotropy Probe (WMAP), from the NASA WMAP Science Team website (white labels). According to HGD cosmology (magenta and yellow labels), gravitational structures appeared much earlier than predicted by CDMHC cosmology. From HGD the first stars formed very gently in dense globular star clusters immediately after the transition to gas; that is, in less than a million years. From CDMHC and the Jeans 1902 theory the first stars were enormous ($\text{Mass} \geq 110M_\odot$) and explosive, and could not form for 300 million years to permit sufficient cooling from the Jeans criterion.

The intense starlight from these Population III superstar explosions is excluded because

it is not observed in γ -ray spectra from blazars (Aharonian et al. 2006). Pop. III starbursts should prevent the formation of globular star clusters with their large densities of small ancient stars, and should have contaminated the entire universe with large atomic number chemicals. However, dense molecular clouds form stars with low metallicity, and globular star clusters have low metallicity as expected from HGD.

The Pop. III event is supported by a lack of hydrogen gas in quasar spectra with redshift $z \leq 6$ ($t \geq 300$ Myr) termed the “Gunn-Peterson trough” (predicted in 1965) attributed to reionization of the gas by Pop. III stars, but this observation can also be explained by HGD cosmology that predicts by this time most of the primordial H-He gas should be condensed and frozen as planets in protoglobularstarclusters and thus undetectable in such quasar spectra. Evidence of metallicity in distant quasars is taken as evidence of Pop. III stars, but is equally explained by HGD formation of a relatively small number of Pop. III explosive stars near protogalaxy centers as the density increases from enhanced rates of PGC and PFP mergers.

Figure 3 shows a Hubble Space Telescope Advanced Camera for Surveys (HST/ACS) image of the Tadpole galaxy merger (Gibson & Schild 2003). One CDMHC cosmology interpretation is that the filamentary galaxy VV29b is a collisionless “tidal tail” triggered by the close passage of the small galaxy VV29c near the larger galaxy VV29a, which flings VV29c far into the background without frictional losses (Briggs et al. 2001). Dust trails show the VV29cdef fragments have frictionally merged into embedded positions. This is confirmed by observations in a variety of infrared bands (Jarrett et al. 2006). Another CDMHC interpretation (Trentham et al. 2001) is that the filamentary galaxy VV29b constituting the tail of the Tadpole has revealed an invisible CDM halo object. Frictionless tidal tail models (Toomre & Toomre 1972) along with frictionless stellar and galactic dynamics models (Binney & Tremaine 1987) conflict with observations and must be abandoned.

The HGD interpretation is that the spiral paths around VV29a are frictional accretion paths of galaxy fragments VV29cdef revealed by star formation in the VV29a baryonic dark matter halo. This interpretation is strongly supported by the 42-48 young globular star clusters arranged precisely in a row pointing to the point of frictional capture of VV29c, and by the high resolution HST images that show VV29c is embedded in VV29a, not far in the back. The extent of the BDM halo of VV29a is shown to be 4×10^{21} m (130 kpc) by the Tadpole merger system. This indicates a frozen PGC diffusivity of about 10^{27} m²s⁻¹.

The inset in Fig. 3 lower left shows an example of the chain galaxies visible in the Tadpole image (circle) of a chain clump cluster (Elmegreen et al. 2005a; Elmegreen et al. 2005b). From HGD cosmology, this linear configuration of the dimmest galaxies of the HST ultra-deep-field supports the idea that galaxies were formed by fragmentation along turbulent

vortex lines in the plasma epoch, as shown in Fig. 1. As the PGCs freeze they diffuse into BDM halos with size $L_{SD} \approx [Dt]^{1/2}$. The luminous halos of the chains of clumps are interpreted as stars and YGCs triggered into existence by tidal forces of the protogalaxy separations.

4. Conclusions

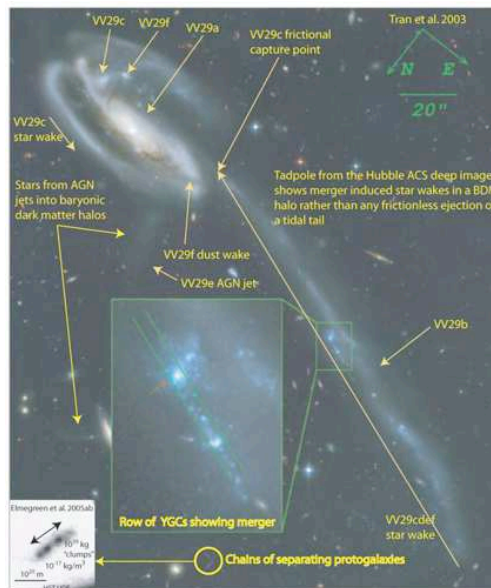
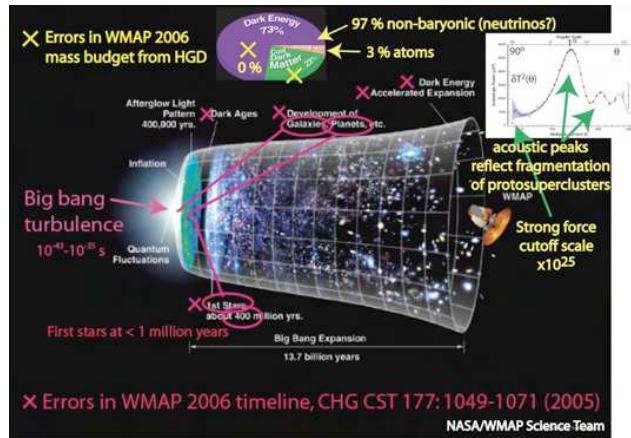
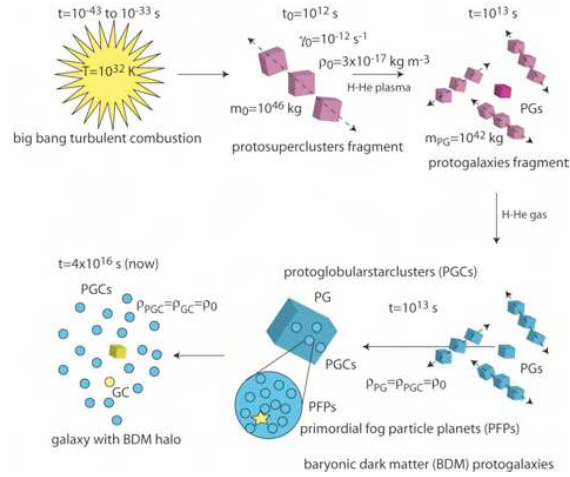
The standard CDMHC cosmology, the Jeans 1902 criterion for gravitational structure formation and the “collisionless” concepts of galactic dynamics (Binney & Tremaine 1987) and frictionless tidal tail formation (Toomre & Toomre 1972) are in fundamental conflict with modern fluid mechanics and make predictions that are increasingly in conflict with observations, eg. (Aharonian et al. 2006) and Fig. 3. They must be abandoned. The Jeans theory and CDMHC cosmology have been modified and extended to include important effects of quantum gravity, viscosity, turbulence, fossil turbulence and diffusion on gravitational structure formation and cosmology in a new paradigm termed hydro-gravitational-dynamics, or HGD (Gibson 1996; Gibson 2000; Gibson 2004; Gibson 2005; Gibson 2006).

The predictions of HGD about the formation of structure are very different from those of CDMHC, as shown in Fig. 1 and Fig. 2. From HGD, the largest structures form first rather than last as predicted by CDMHC. Galaxies and clusters of galaxies emerge from the plasma epoch in linear morphologies reflecting the weak plasma turbulence that triggered their fragmentation, as shown by observations in Fig. 3. The gas universe turned to a fog of planetary mass clouds (PFPs) in protoglobularstarcluster clumps (PGCs) that persist as the baryonic dark matter (BDM), as observed from quasar microlensing (Schild 1996). Because all stars form from planets in dense clumps according to HGD, it is easy to explain claims of dark energy and accelerating rates of the universe expansion as due to dimming effects of the BDM. Linear strings of stars and young globular clusters of stars are shown in the Tadpole system in Fig. 3 that clearly demonstrate the frictional accretion of galaxy fragments, and the large extent of the BDM halo formed by frozen PGCs diffusing away from the original dense protogalaxy.

Chain galaxies detected in the HST/ACS Tadpole images, Fig. 3, are interpreted as chains of protogalaxies formed by gravitational fragmentation along turbulent vortex lines in the last stages of the plasma epoch according to HGD, Fig. 1. Luminous halos of the massive star clumps reflect star formation by tidal forces of the separation triggered in the dark PGCs of the BDM protogalaxy halos.

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(top) 1. Formation of gravitational structure according to hydro-gravitational-dynamics (HGD) theory (modification of Fig. 1 in Gibson 2006). A turbulent instability causes the big bang (Gibson 2004; Gibson 2005), upper left. Fossil temperature turbulence fluctuations produce density patterns that trigger gravitational fragmentation along turbulent vortex lines at protosupercluster scales, top center, and protogalaxy scales, top right (Gibson 1996; Gibson 2000). When the plasma turns to gas the viscosity and fragmentation scales decrease, top and bottom right, causing fragmentation at PGC globular cluster and PFP planet scales to form the BDM and the first small stars, bottom center. The dense, dark, PGCs have now diffused to form large dark matter galaxy halos, bottom left.

(middle) 2. NASA/WMAP Science Team mass budget (top) and timeline for gravitational structure formation (white captions) based on the standard CDMHC cosmology, compared to predictions (yellow and magenta captions) from HGD cosmology (Gibson 1996; Gibson 2000; Gibson 2004; Gibson 2005). The acoustic peaks in the anisotropy power spectrum (upper right) are interpreted as a reflection of protosupercluster fragmentation, as shown in Fig. 1.

(bottom) 3. The “Tadpole” galaxy reveals the frictional baryonic dark matter halo of galaxy VV29a by the star and young globular cluster wakes produced as galaxy fragments VV29cdef merge forming the filamentary galaxy VV29b (Gibson & Schild 2003). Chains of proto-galaxies (insert lower left) reflect their gravitational fragmentation along turbulent vortex lines of the plasma. The glow reveals frictional formation of YGCs in the baryonic dark matter halos of the PGs as they separate in the gas epoch due to the expansion of the universe (Gibson 2006).

Table 1. Length scales of self-gravitational structure formation

Length scale name	Symbol	Definition ^a	Physical significance ^b
Compton wavelength	L_C	$hm^{-1}c^{-1}$	wavelength of particle with mass m
Schwarzschild radius	L_S	Gmc^{-2}	size of non-spinning black hole of mass m
Planck length	L_P	$[c^{-3}hG]^{1/2}$	scale of big bang vacuum instability
Jeans Acoustic	L_J	$V_S/[\rho G]^{1/2}$	ideal gas pressure equilibration
Schwarz Diffusive	L_{SD}	$[D^2/\rho G]^{1/4}$	V_D balances V_G
Schwarz Viscous	L_{SV}	$[\gamma\nu/\rho G]^{1/2}$	viscous force balances gravitational force
Schwarz Turbulent	L_{ST}	$\varepsilon^{1/2}/[\rho G]^{3/4}$	turbulence force balances gravitational force
Kolmogorov Viscous	L_K	$[\nu^3/\varepsilon]^{1/4}$	turbulence force balances viscous force
Ozmidov Buoyancy	L_R	$[\varepsilon/N^3]^{1/2}$	buoyancy force balances turbulence force
Particle Collision	$L_{Col.}$	$m\sigma^{-1}\rho^{-1}$	distance between particle collisions
Hubble Horizon	L_H	ct	maximum scale of causal connection

^a V_S is sound speed, ρ is density, D is the diffusivity, $V_D \equiv D/L$ is the diffusive velocity at scale L , $V_G \equiv L[\rho G]^{1/2}$ is the gravitational velocity, γ is the strain rate, ν is the kinematic viscosity, ε is the viscous dissipation rate, $N \equiv [g\rho^{-1}\partial\rho/\partial z]^{1/2}$ is the stratification frequency, g is self-gravitational acceleration, z is in the opposite direction (up), m is the particle mass, σ is the collision cross section, c is light speed, h is Planck's constant, G is Newton's constant, t is the age of universe.

^bMagnetic and other forces (besides viscous and turbulence) are negligible for the epoch of primordial self-gravitational structure formation (Gibson 1996).